Electronic Properties of the NREL Low Filament Temperature HWCVD Amorphous Silicon Germanium Alloys

Shouvik Datta and J. David Cohen

Department of Physics, University of Oregon

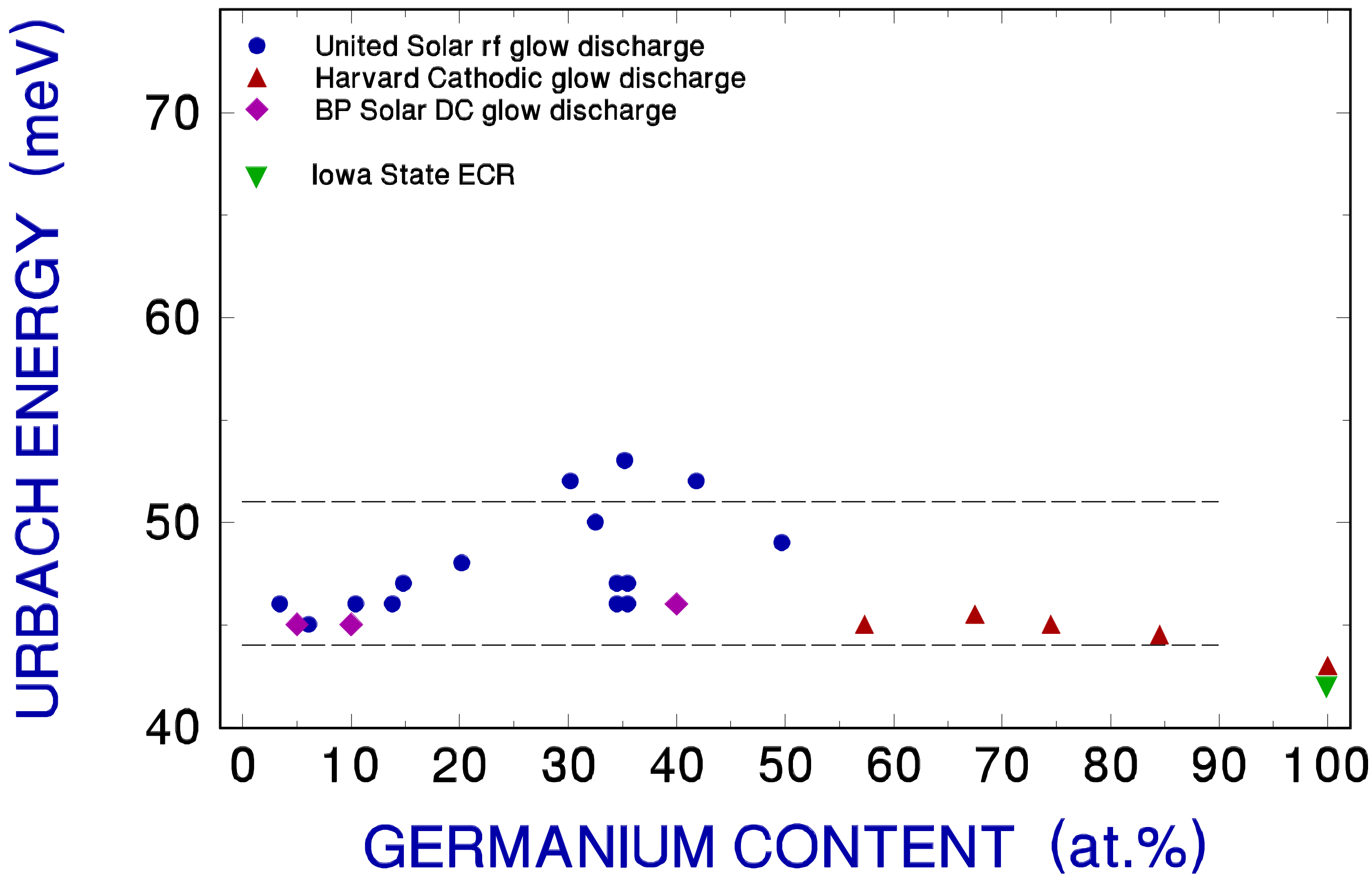
with

Yueqin Xu and Harv Mahan

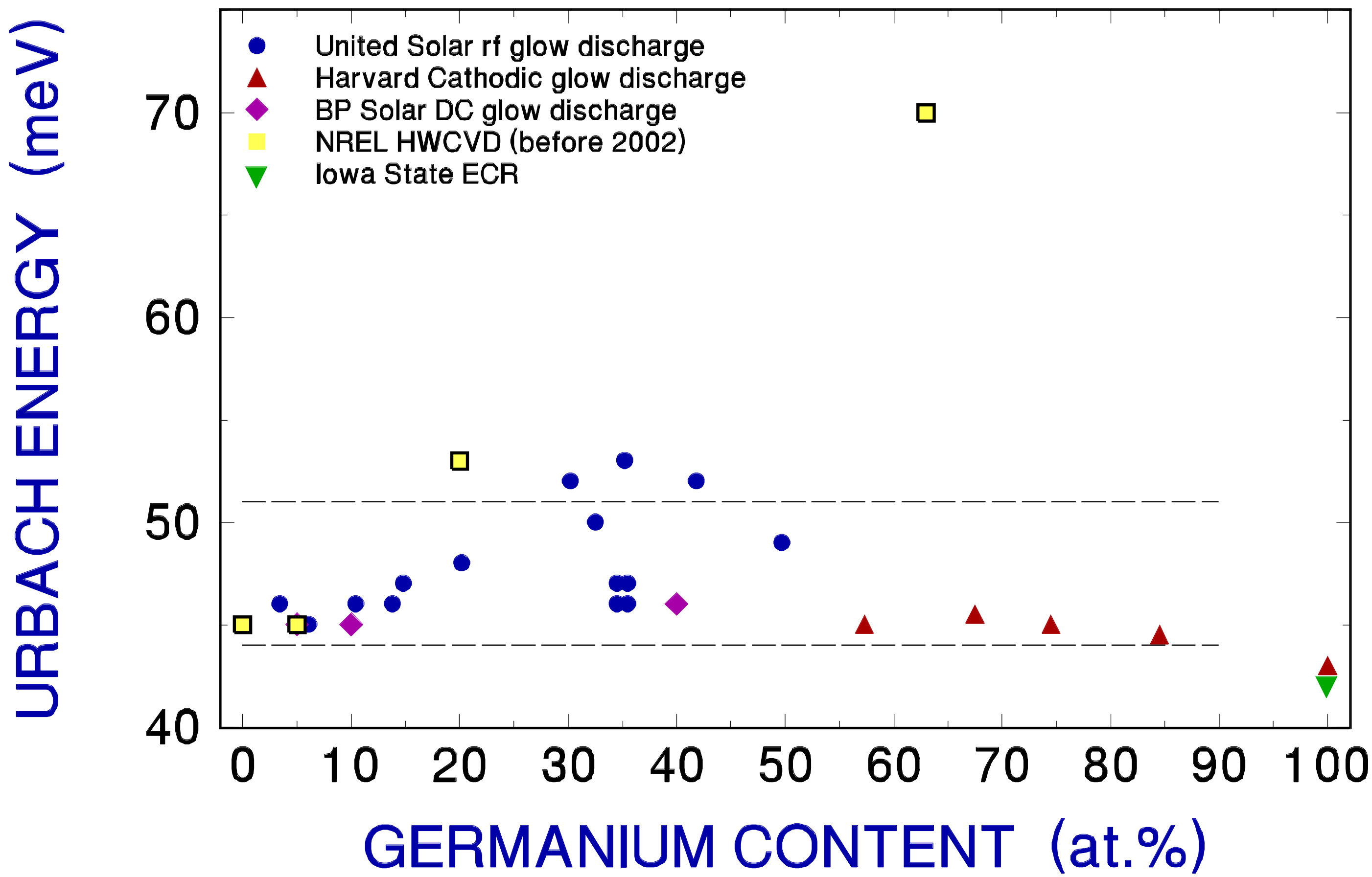
National Renewable Energy Laboratory

Work at Oregon under **NREL Subcontract ADJ-2-30630-17**

Urbach Energies for the Best a-Si,Ge:H



The Best PECVD vs. HWCVD a-Si,Ge:H

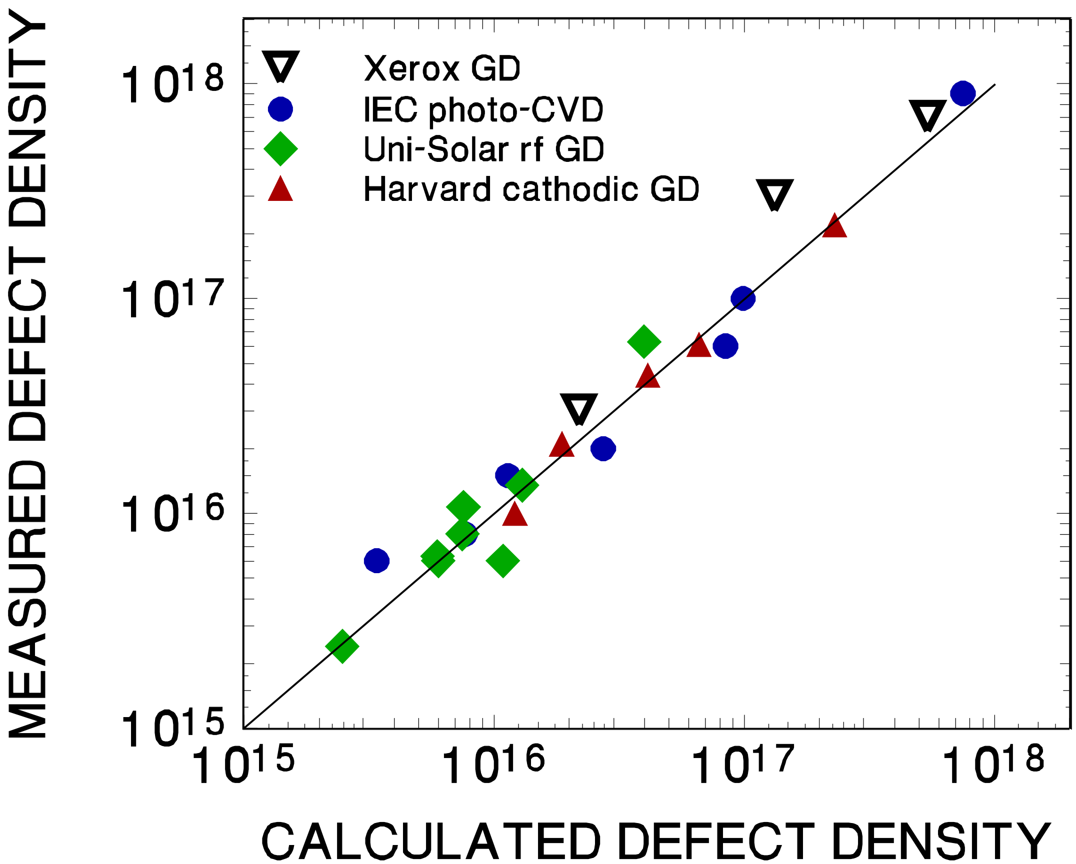


Urbach Energy plus Gap Energy Determines Defect Density

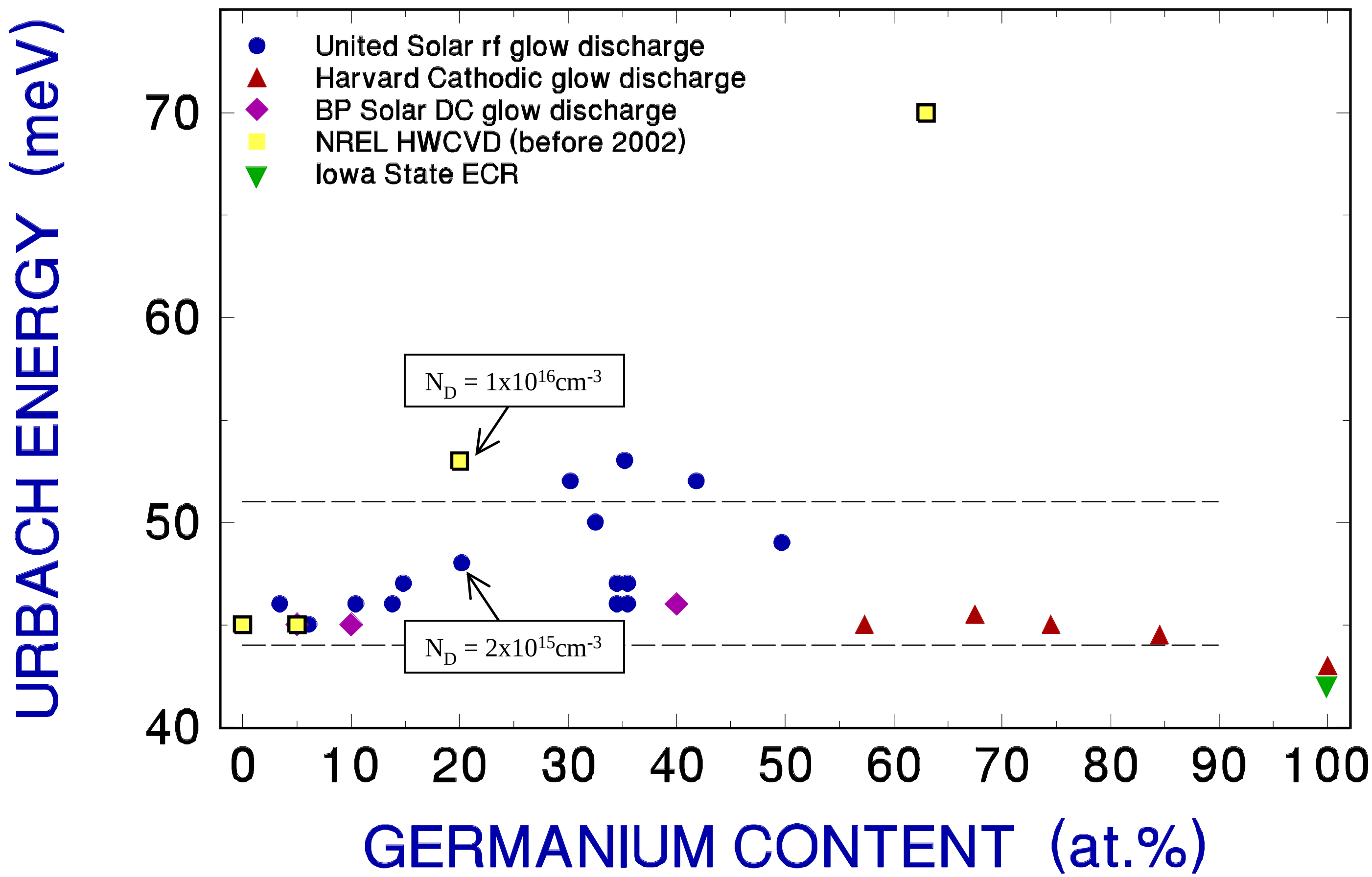
$N_D = N_0 E_U \exp[-(E_D - E^*)/E_U]$ [1]

- Single choice of N_0 and E* used for all sets of samples
- The germanium fraction of these alloys varies between 0.2 and 1.0.

[1] M. Stutzmann, Philos. Mag. B**60**, 531 (1989)

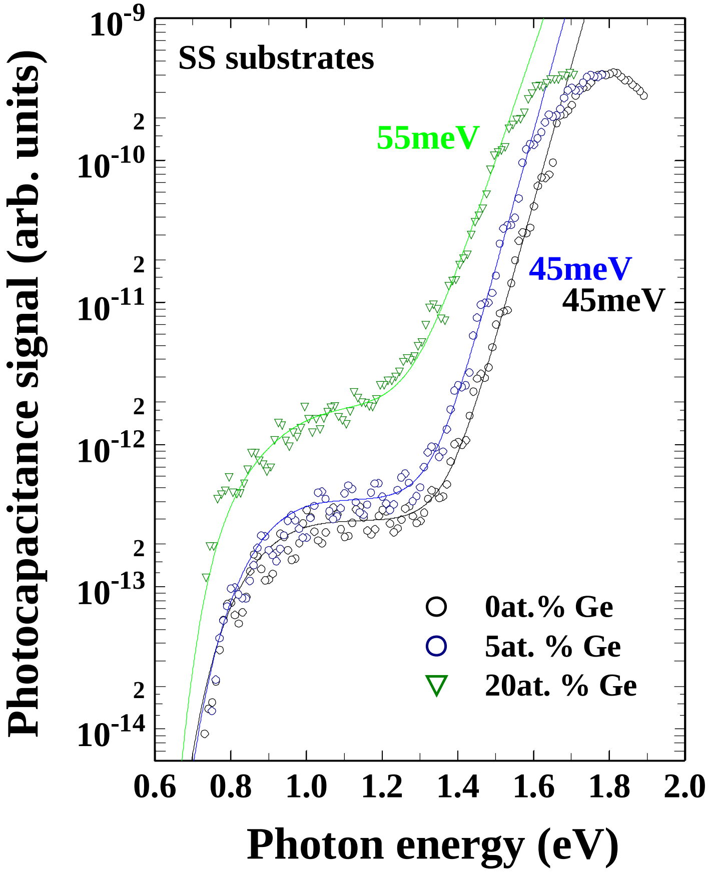


The Best PECVD vs. HWCVD a-Si,Ge:H



Spectra for NREL HWCVD a-Si,Ge:H

2000°C Tungsten Filament

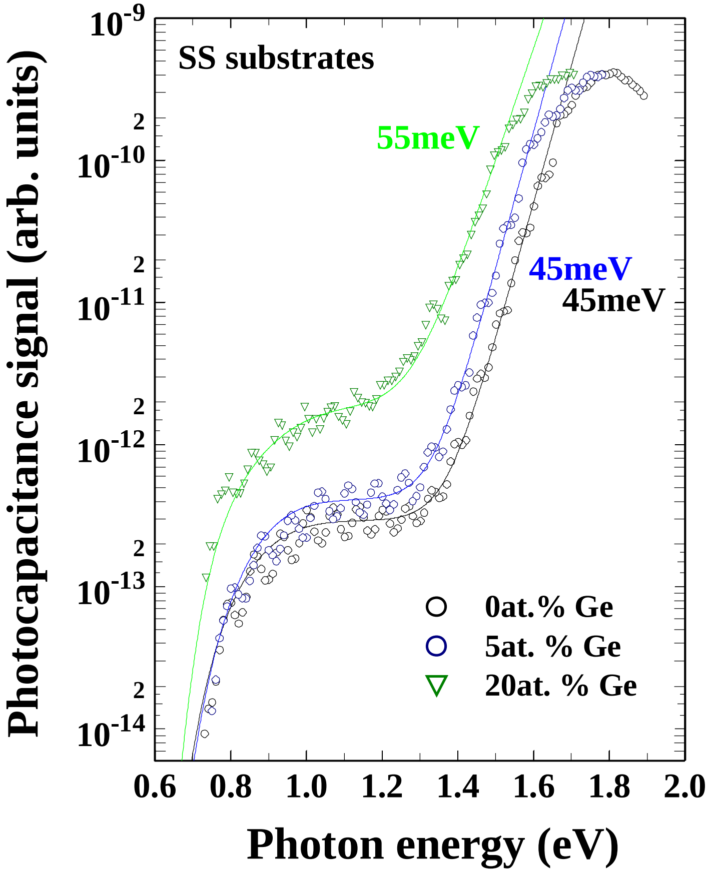


Best HWCVD
Samples prior to 2004

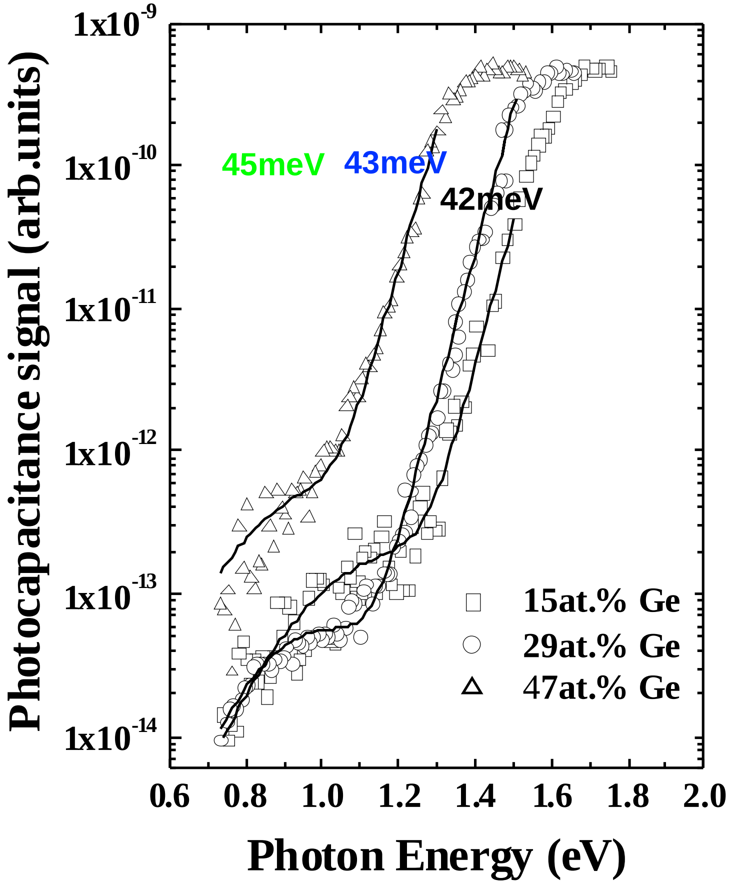
Does this mean that Ion Bombardment is crucial for high quality a-Si,Ge:H?

Spectra for NREL HWCVD a-Si,Ge:H

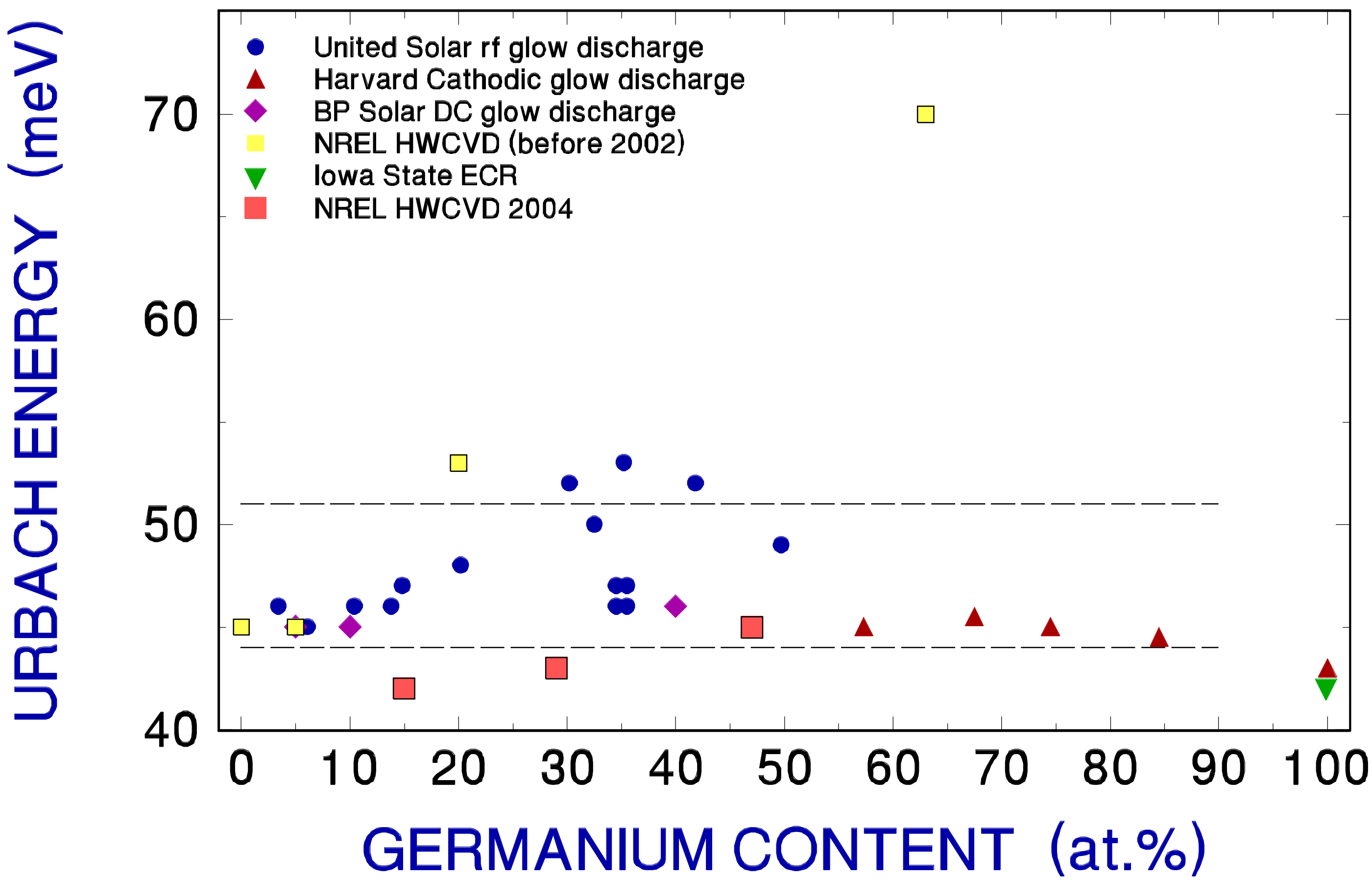
2000ºC Tungsten Filament



1800ºC Tantalum Filament



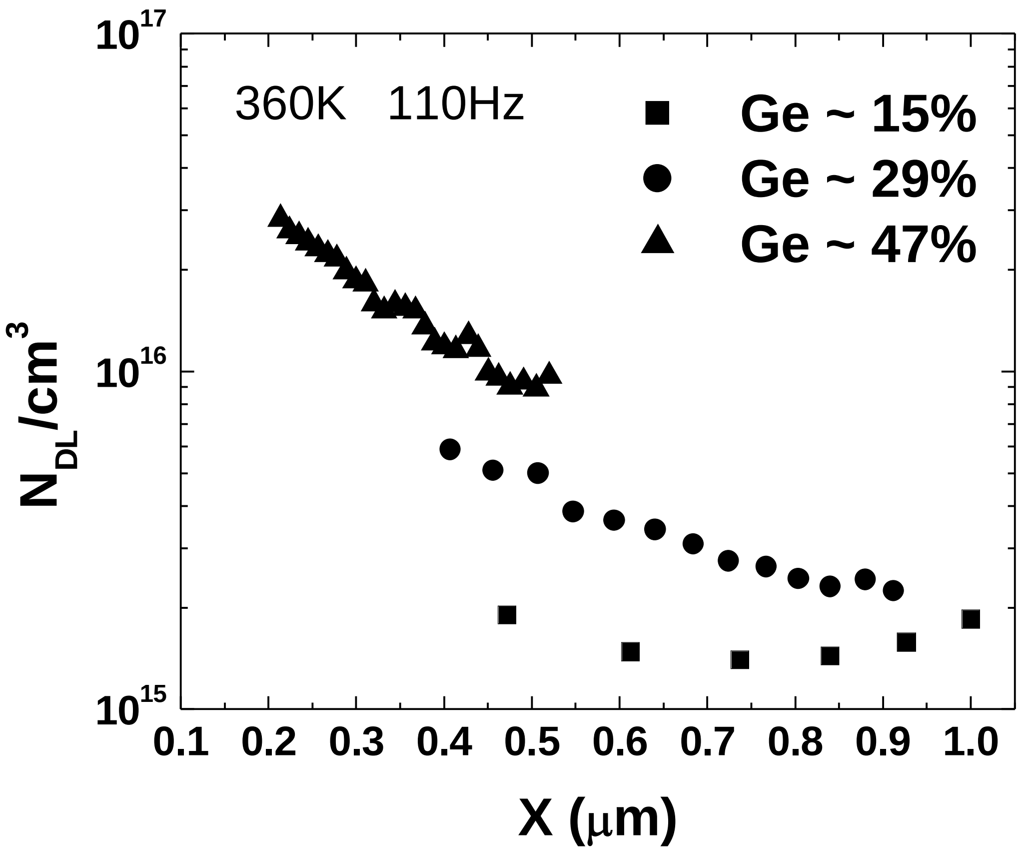
The Best PECVD vs. HWCVD a-Si,Ge:H



Mid-gap Defect Density Profiles via DLCP

Note that N_D increases in the direction of film growth

This reflects the fact that the substrate temperature increased as much as 90°C during growth



Properties of New HWCVD a-Si,Ge:H Alloys

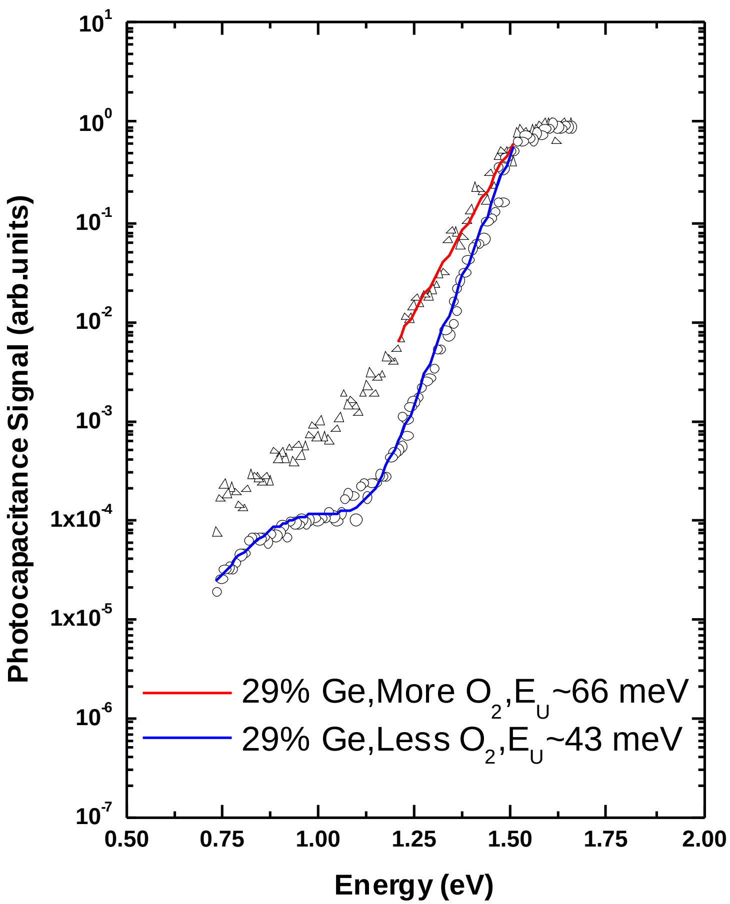
New NREL HWCVD a-Si,Ge:H alloys exhibit electronic properties as good as any alloys ever characterized

Sample	Ge Fraction (at.%)	Growth Rate (Å/s)	E_{04} (eV)	E_{Tauc} (eV)	E_U (meV)	Defect Density (cm^{-3})
L1305	15	1.39	1.79	1.65	42 ± 2	2×10^{15}
L1306	29	1.78	1.66	1.50	43 ± 3	$4 \pm 2 \times 10^{15}$
L1307	47	2.00	1.47	1.32	45 ± 2	$2 \pm 1 \times 10^{16}$

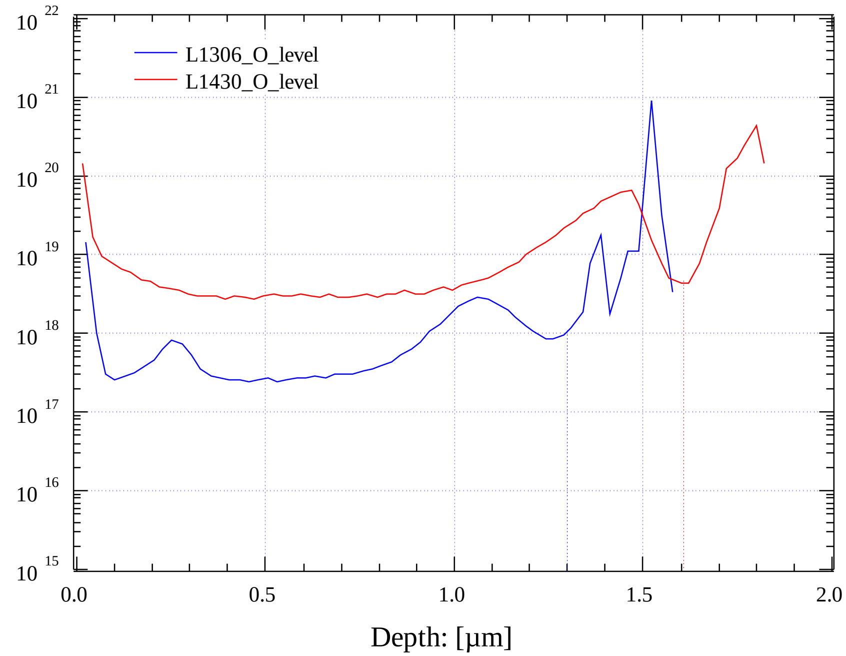
- **Urbach energies from Photocapacitance Spectra**
- **Midgap Defect densities from DLCP measurements**
- **Note relatively high growth rates**

Recent Samples Exhibit Poorer Properties

Photocapacitance Spectra: 29at.% Ge

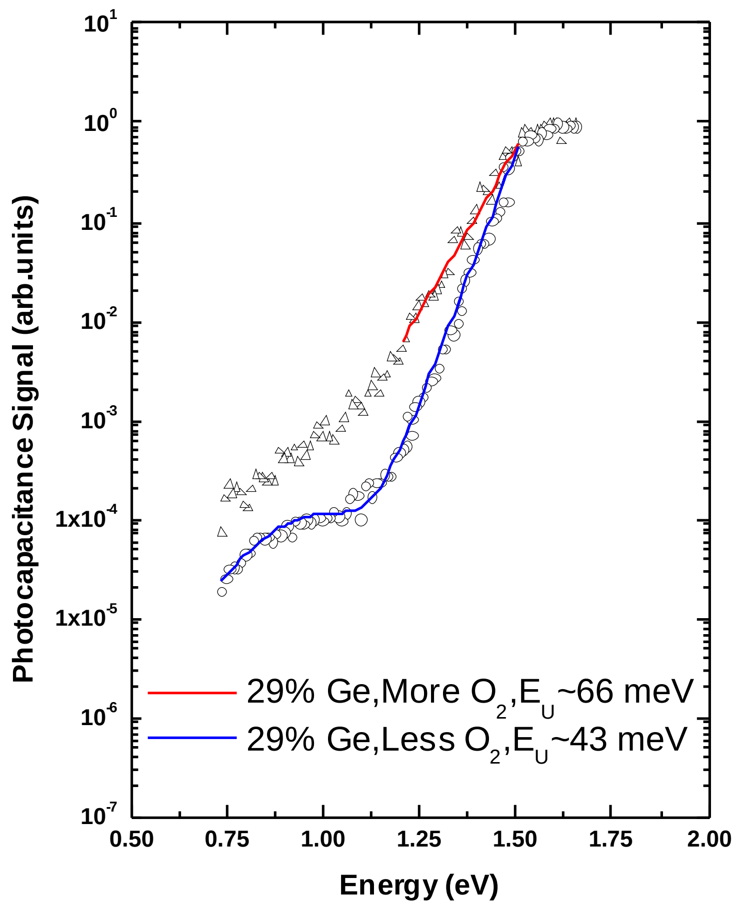


Oxygen SIMS Profiles

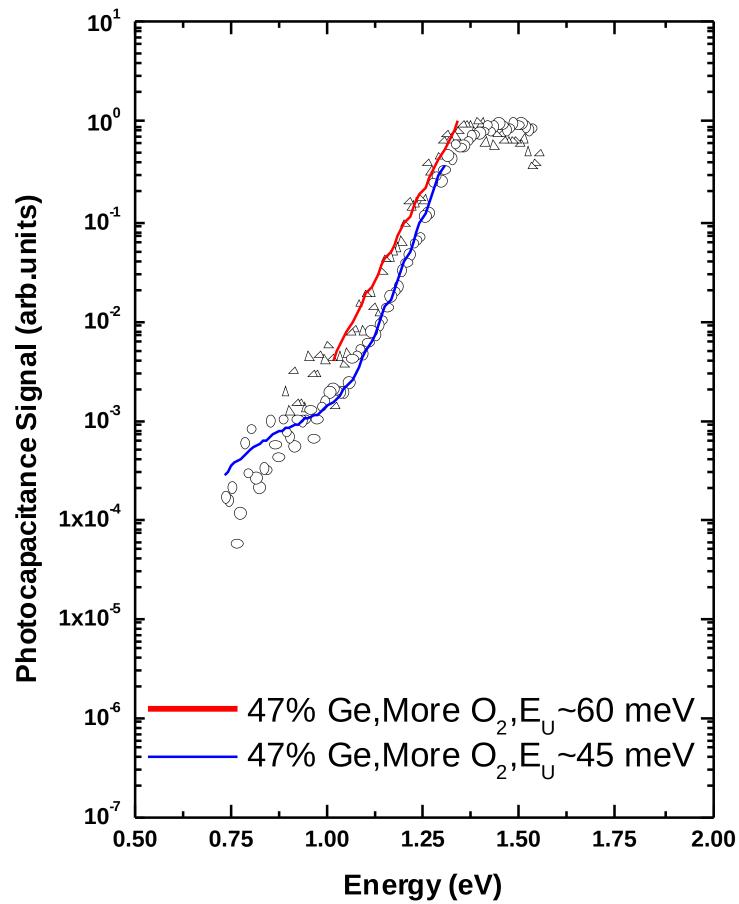


Recent Samples Exhibit Poorer Properties

Photocapacitance Spectra: 29at.% Ge



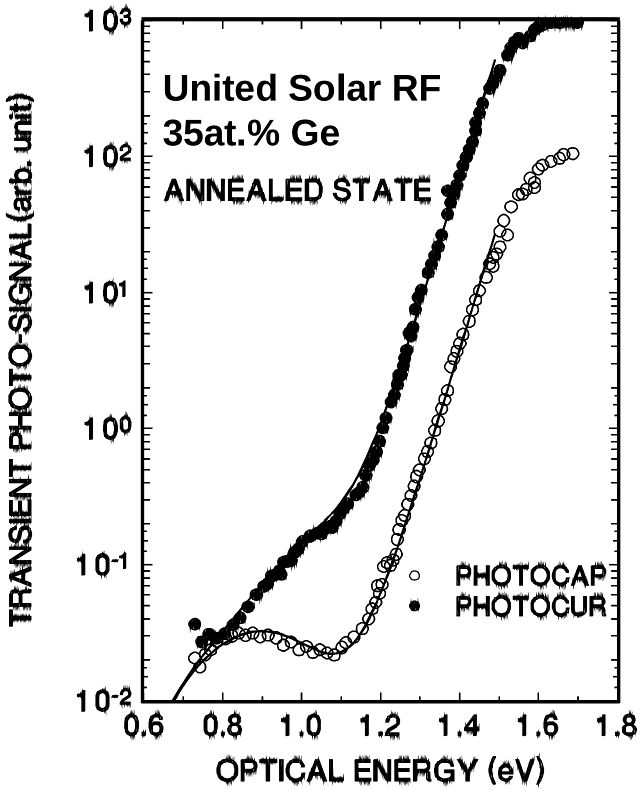
47at.% Ge

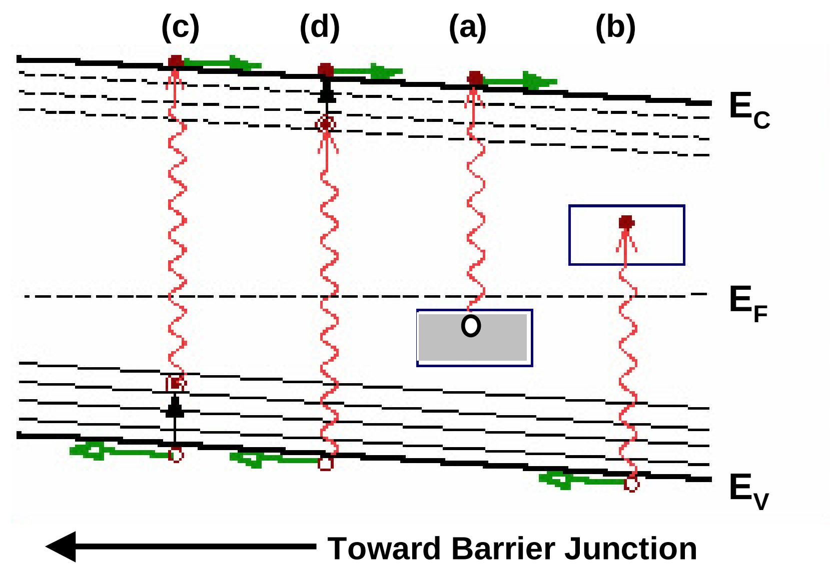


UNIVERSITY OF OREGON DEPARTMENT OF PHYSICS

Measuring Fraction of Collected Holes

Obtained from Ratio of TPI to TPC signals in Bandtail Region

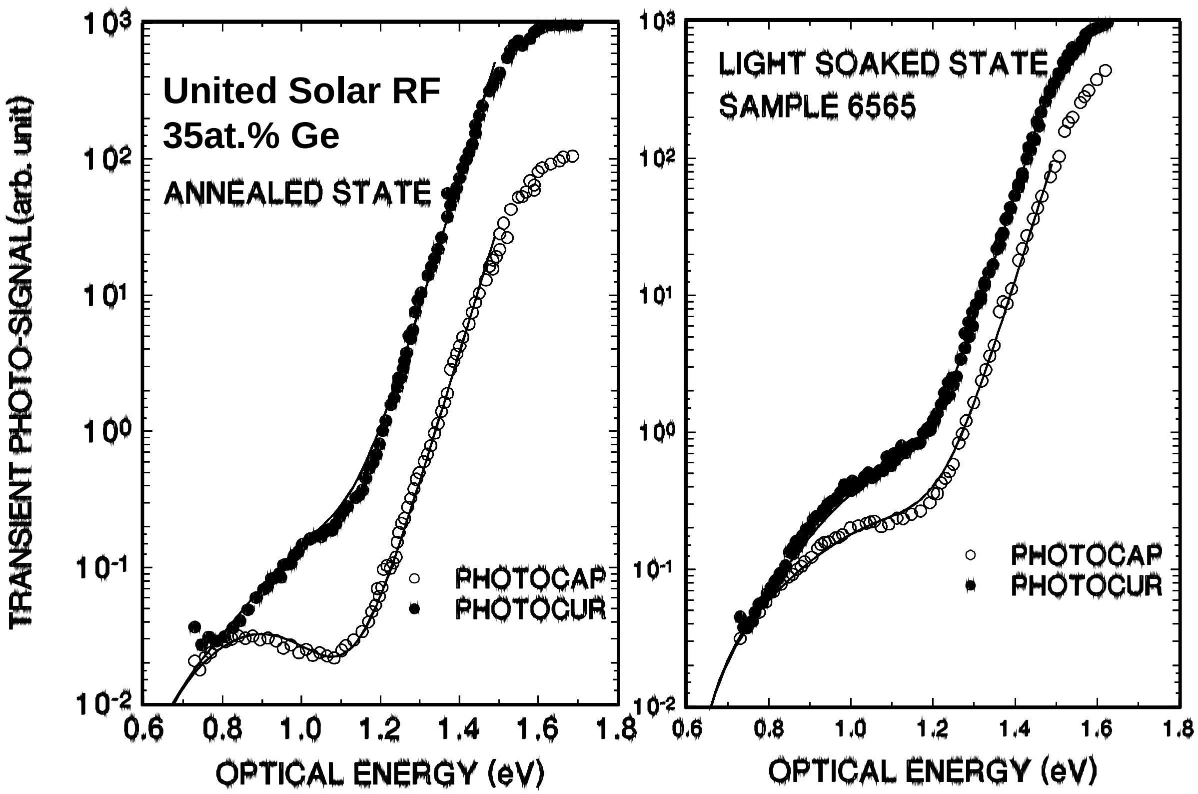




For this United Solar sample the hole collection fraction exceeds 90% under our experimental conditions

Measuring Fraction of Collected Holes

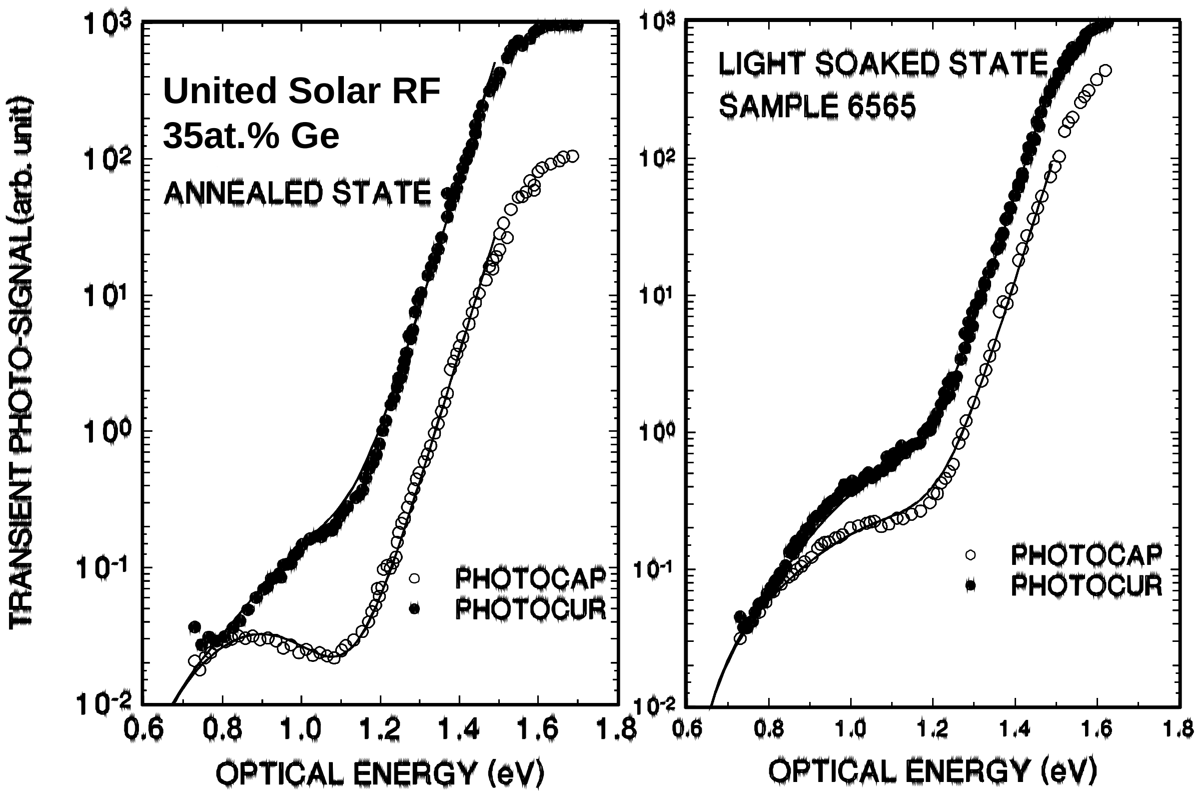
United Solar RF PECVD 35at.% Ge Sample

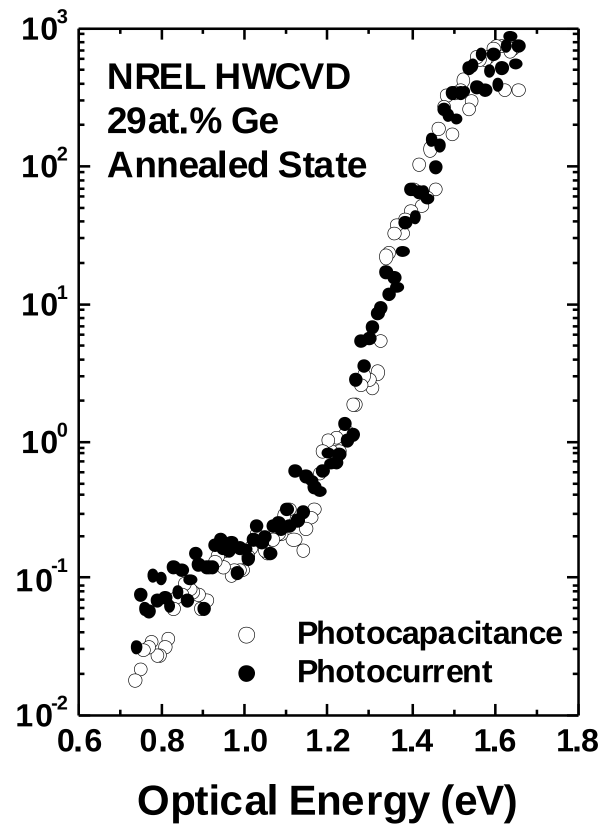


Hole Collection: 90% 66%

Measuring Fraction of Collected Holes

United Solar RF PECVD 35at.% Ge Sample **NREL HWCVD 29at.% Ge**





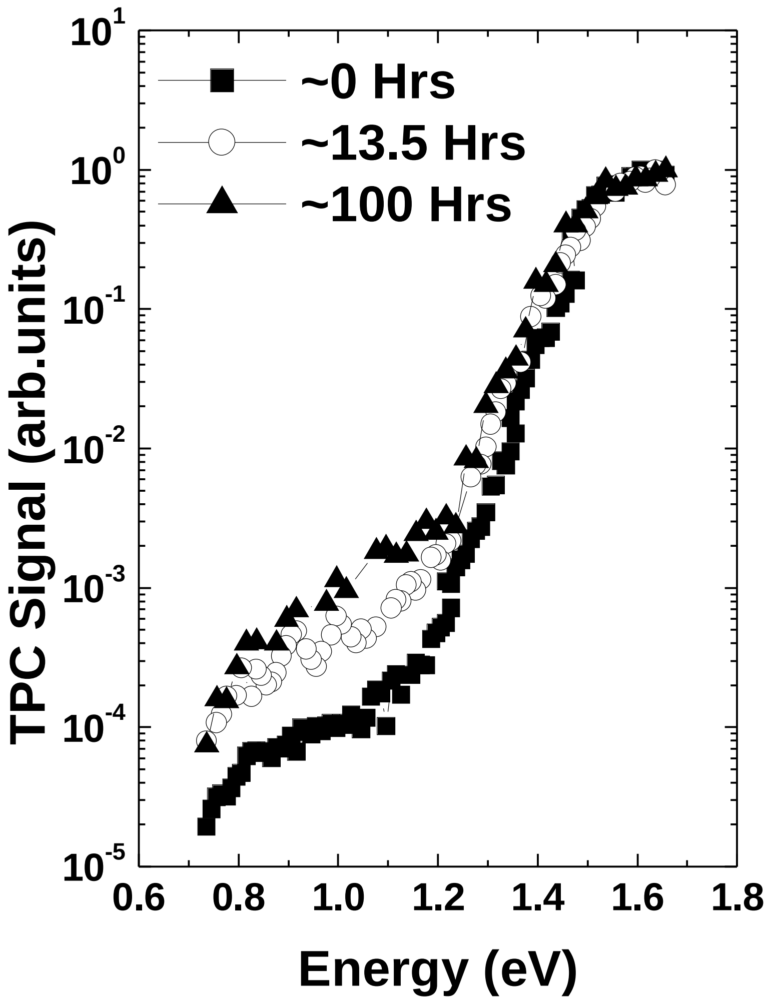
Hole Collection: 90% **66%** **Very small ?**

Light-Induced Degradation

29at.% Ge sample was exposed to 610nm filtered ELH light at 800mW/cm^2

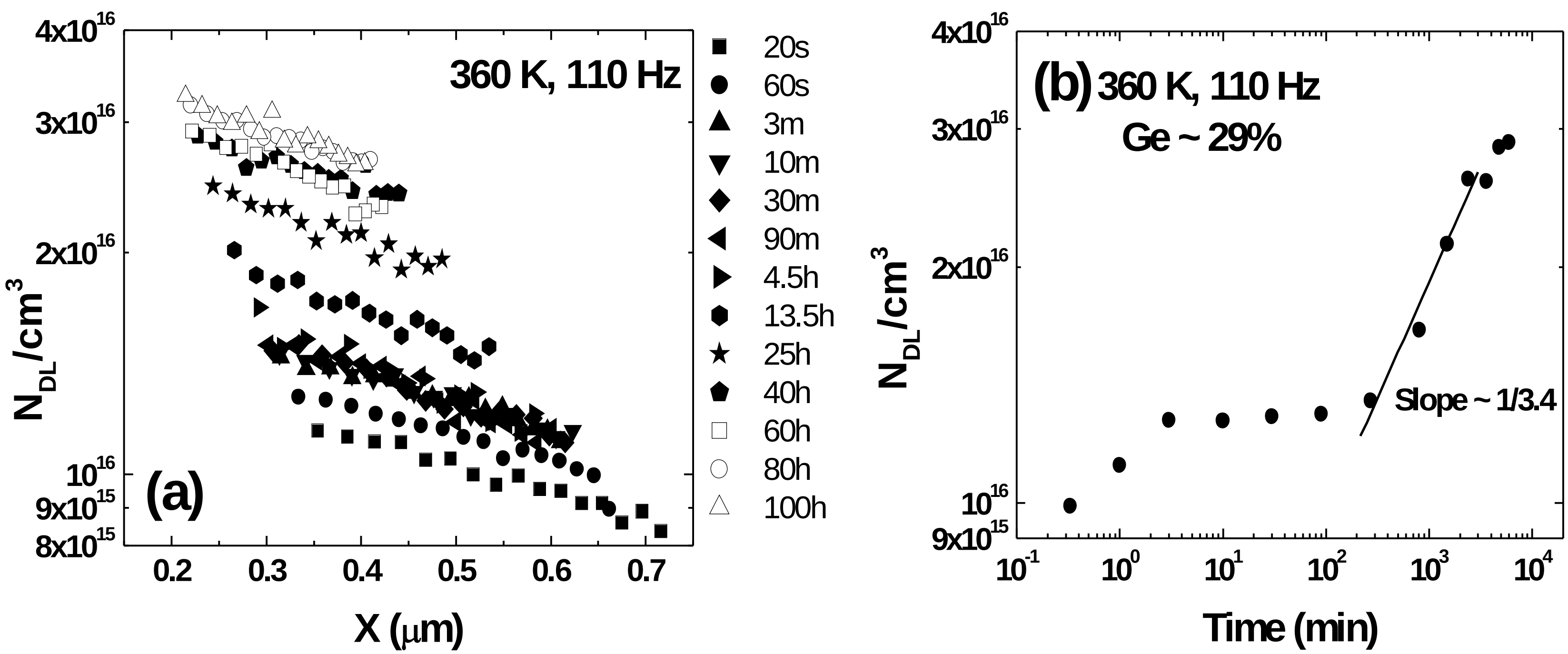
Increase in deep defect density clearly occurs by a substantial factor

Unusual creation kinetics are revealed by DLCP studies



Unusual Defect Creation Kinetics in 29at.% Ge Alloy

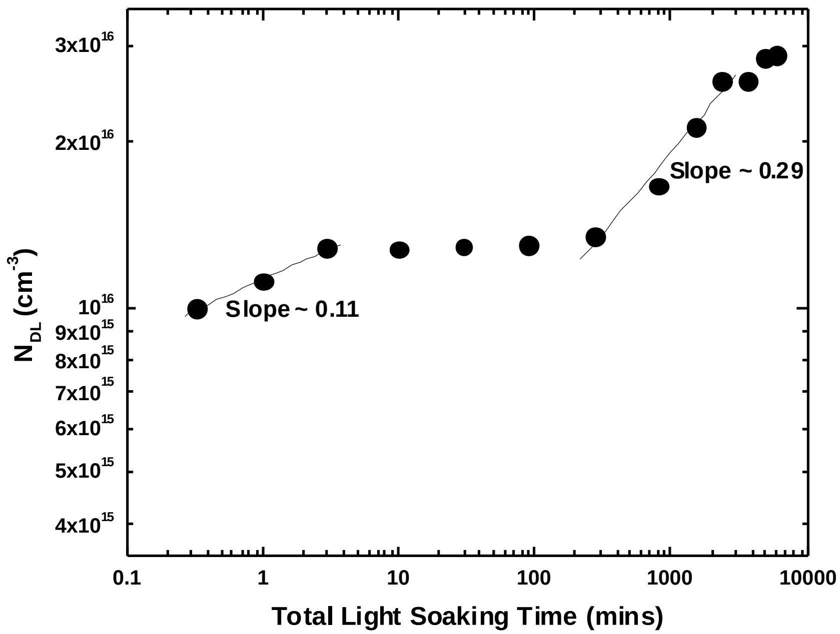
Defect density increases by a factor of 1.4 during first 10 minutes and then remains constant for next 3 hours of light exposure before increasing again



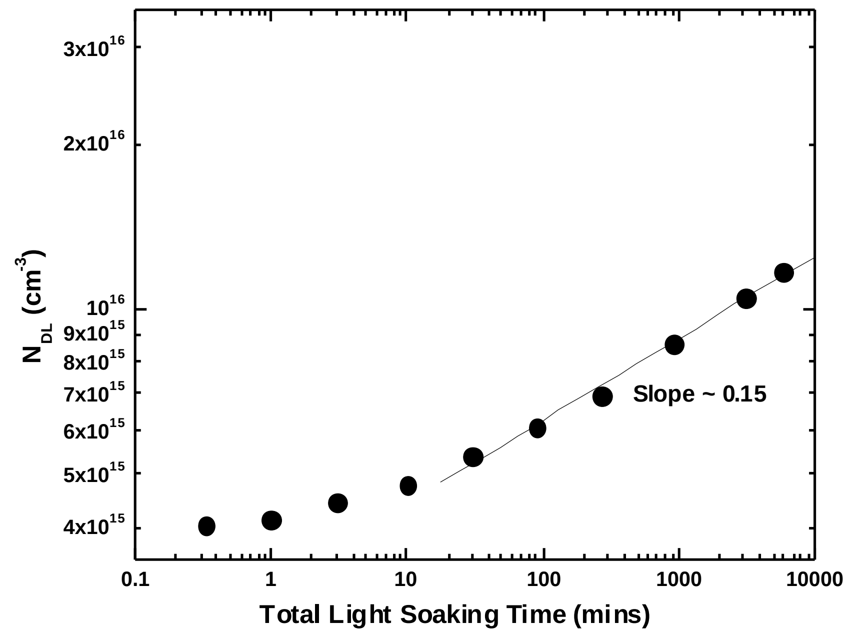
Subsequent defect creation exhibits a nearly $t^{0.33}$ time dependence

Comparison with PECVD Alloy Degradation

NREL 29at.% Ge HWCVD Alloy



USOC 30at.% Ge PECVD Alloy



Note: Slightly higher defect levels in HWCVD alloy sample are likely due its slightly smaller energy gap.

Conclusions

- We have found superior electronic properties for NREL HWCVD a-Si,Ge:H alloys grown using lower filament temperatures.
- In particular these samples exhibit sharp band tails and low midgap defect densities, comparable to the best PECVD a-Si,Ge:H samples.
- Electronic properties appear to be very sensitive to oxygen impurity levels, perhaps much more so than PECVD alloy samples.
- The minority hole collection appears to be less efficient than the best PECVD alloys in apparent contradiction to the above results.
- Preliminary degradation studies of the 29at.% Ge alloy sample indicate an unusual two-step defect creation kinetics.